Implementation and Research on the Operational Use of the Mesoscale Prediction Model COAMPS in Poland

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LONG-TERM GOALS

Our long-term goal is to implement an operational high-resolution atmospheric data assimilation and prediction system and to use it for daily weather forecasting. To date we have worked on several operational and scientific aspects of the problem using the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS®[1]): (a) setting up stable large scale data transfer capabilities to facilitate COAMPS runs 2-4 times per day in an operational manner for different geographical regions and using different nested grid configurations; (b) perform research on the MPI scalability of COAMPS on selected computer architectures and to optimize the code to take advantage of the vector capabilities of the Cray X1 and the massively parallel features of our Linux cluster; (c) identify and understand the uncertainties in high-resolution NWP forecast and their impact on severe weather, such as extreme rainfall, and to develop model metrics appropriate to mesoscale, detailed weather forecasts; and (d) improve our knowledge of observational error characteristics for spatially correlated data and develop the numerical schemes capable of assimilating these types of observations.

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OBJECTIVES

The objectives of this project are to: (a) implement an operational data feed from the Navy Operational Global Atmospheric Prediction System (NOGAPS), and implement a semi-operational version of COAMPS at the Interdisciplinary Centre for Mathematical and Computational Modelling (ICM), Warsaw University; (b) validate COAMPS model performance through inter-comparisons with statistics obtained from the United Kingdom Meteorological Office (UKMO) unified model; (c) investigate the scalability of COAMPS on ICM computers, a 200-processor OPTERON cluster and a Cray X1; and (d) develop a data assimilation scheme that can assimilate remotely-sensed and non-conventional data sources with a special emphasis on Doppler radar data. Meeting these objectives will allow the Polish National Air Defense to issue 1-5 day mesoscale weather forecasts in the regions of their interest, including Poland and Central Europe.

APPROACH

Our approach is to utilize NOGAPS for initial and lateral boundary conditions, and COAMPS for mesoscale atmospheric forecasts. The NOGAPS fields are obtained from the Global Ocean Data Assimilation Experiment (GODAE) server at the Fleet Numerical Meteorology and Oceanography Center (FNMOC) and transferred to ICM in automated (machine-controlled) efficient and stable way, thanks to support of FNMOC. We ported the COAMPS system to the ICM Linux cluster and Cray X1 computers and measured system performance and scalability using tools developed in-house for model verification. The unique aspect of our capabilities is that we concurrently run the UKMO mesoscale model on a grid that is similar to the one used by COAMPS. We will also investigate the time evolution of the conditional forecast (background) error probability density function using an ensemble of the model forecast to generate background error statistics. This helps us to identify and understand the uncertainties in high-resolution NWP forecasts on high-impact weather, particularly extreme rainfall. Finally, we will study observational error characteristics of radar reflectivity and radar radial winds. Such observations have the potential to provide detailed information to improve mesoscale analyses and forecasts. We will study historical weather events for which we have radar data to understand the observational error characteristics. We will investigate how they may be applied in data analyses used for assimilating radar data into numerical weather prediction models.

WORK COMPLETED

During FY06 we accomplished the following tasks: (a) made a new set-up of the US NAVY COAMPS system on ICM machines at Warsaw University for the purpose of providing operational support to Polish sailors starting in the pre-olympic regatta in Qingdao (China), (b) developed some preliminary statistics to estimate the quality of the model results in selected regions, (c) investigated the behavior of the background errors in our operational set-up, (d) collected synoptic data and buoy data from the Qingdao region for post analysis of the model results, (e) investigated the impact of the surface temperature and the vertical shear of the zonal wind on the dynamics of a simple two-layer model of the atmosphere (Brojewski et al., 2006), (f) worked on improving the pre-conditioning of the system of analysis equations used in the 3D-VAR assimilation system NAVDAS, and (g) worked on the development of the ensemble Kalman filter approach for the purpose of assimilating radar reflectivity and radial wind data in COAMPS.

RESULTS

During FY06, we implemented the COAMPS atmospheric model on several computer architectures, investigated model scalability including MPI, established operational procedures, wrote a graphical interface, and initiated large-scale data transfers from the GODAE data server. This enables us to run the COAMPS system in a quasi-operational mode. This quasi-operational set-up consists of 5 nested grids with forecasts ranging from 36 hours for Poland, 48h for Iraq and Afghanistan, 72h for Central Europe, and 120h (5 days) for the coarse-mesh North Atlantic-West European-West Asia region. Most of our data has been archived, so we are able to rerun the model for interesting cases and to evaluate the quality of our forecast for longer periods.

Since August 2006, we have been running an area over Qingdao operationally. This set-up consists of four grids with resolution ranging from 32.4 km for outermost coarse grid to 1.2 km on the finest-scale grid. We have concentrated on validating the wind and temperature, since these parameters are most important for the sailors. We developed scripting software to control the data transfer, forecast runs, and graphical post-processing of the results. All model data were presented on a specially designed web page, available for the duty forecaster (in our case Piotr Flatau) located at the venue of the regatta. Beside the static pictures, our www olympic page also includes animations of wind and temperature fields for the two finest grids. All these tools were used by the duty forecaster, who, after analyzing the meteorological situation, gave his synoptic interpretation of the weather and presented his evaluation to sailors and trainers daily at weather briefings. Only a few teams (British and Americans among others) have meteorologists on their team. British duty forecasters use the MM5 model, while other organizers presented results of the Weather Research and Forecast (WRF) model. Results of COAMPS, when compared with the other NWP models used, were encouraging. In some cases, our duty forecaster, was able to correctly forecast the start of the breeze based on COAMPS results, when the other models did not forecast a such event.

Fig. 1 shows two snapshots from our regatta www page. The picture on the left presents forecast of air temperatures and streamlines over outermost 32.4 km grid. Picture on the right, presents wind direction (arrows) and wind velocity (in color) in finest 1.2 km grid. Differences in velocity over open sea and coastal waters are evident, and the complex mesoscale structure of the wind field is noted.

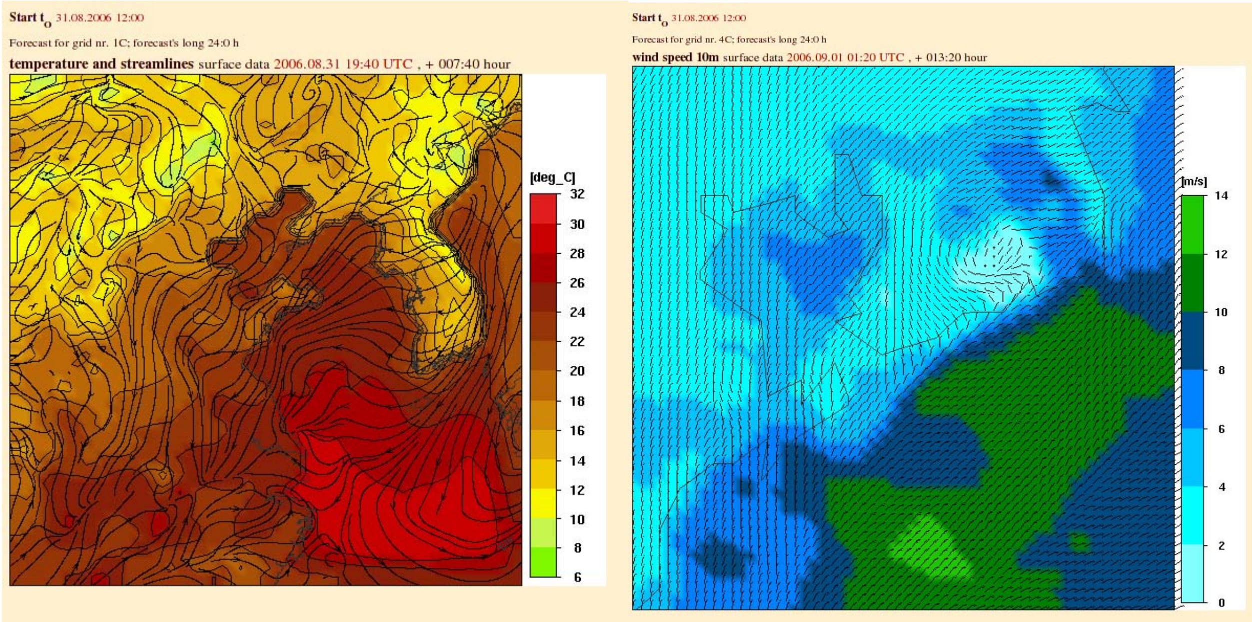

Fig. 1. Example of the COAMPS forecasts for the coarse (left panel) and finest (right panel) grids. The coarse grid this is the 7h 40m forecast of air temperature and stream lines at the 2 m level is shown for the coarse grid, while the 13h 20min forecast of the wind speed and wind direction at 10 m level is shown for the fine grid. In both cases the starting time is 12UTC 31 Aug 2006.

We concentrated on the development of verification tools for our operational runs this year. We started from commonly used indices such as mean error, root mean square error, and bias. Figure 2 shows the dependence of the mean error on the length of the forecast. Data are from the operational set-up for grid 2 (Central Europe, 169x223 grid points, 13 km grid spacing). All available cases in July 2006 are presented. The error growth in almost linear, the smallest at the 12h forecast, the largest at the 72h forecast. The magnitude of the error is comparable to the errors produced by other models. An additional error that is noted is the diurnal variation of the mean error, and we suspect that this could be caused by deficiencies in the parameterization of the land processes in the model.

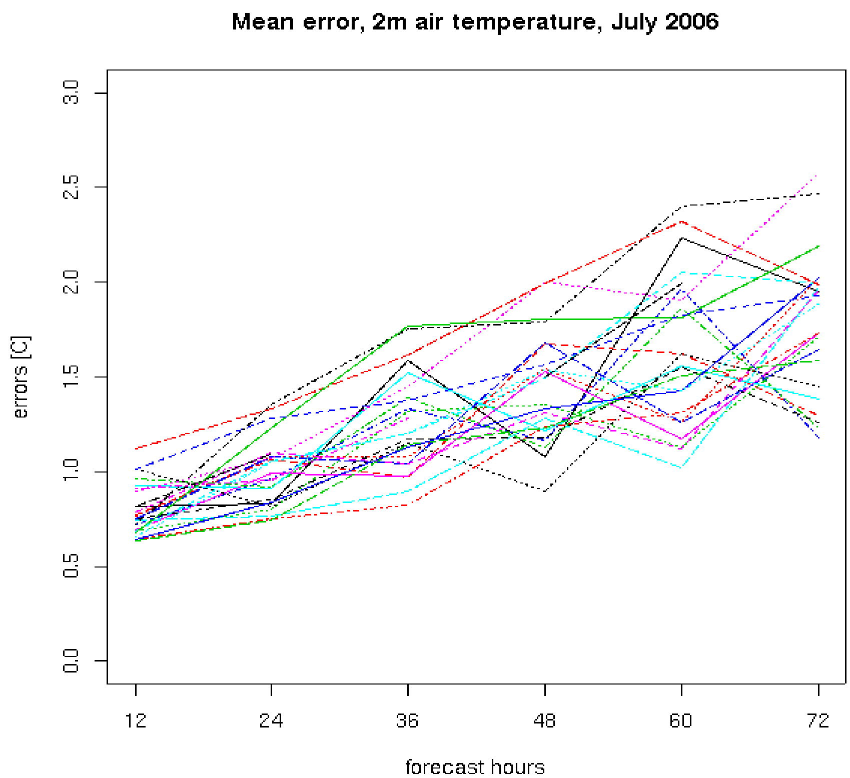

Fig. 2. Dependence of the mean error of the 2 m air temperature on length of the forecast for grid 2, Central Europe region.

Figures 3-5 are produced from data of grid 1 (coarse-mesh North Atlantic-West Europe-West Asia region, 197x123 gridpoints, 39 km horizontal grid spacing). These figures present an alternative method of data verification using the conditional quantile plot (Wilks, 1995). The conditional quantile plot helps to compare the observed and forecast distribution of the evaluated meteorological element. This comparison is performed through the grouping of the observed and forecast data into bins and plotting some quantiles of both distributions. In a perfect case, where the observed and forecast data are from the same distribution, the median (50^{th} quantile) should lie on thin line crossing the picture at equal distance from both axes. In all figures presented, the quantiles give us a compact and an almost complete picture of the relationship between observed and forecast values. Additionally, on each figure, the histogram of the forecast distribution is plotted.

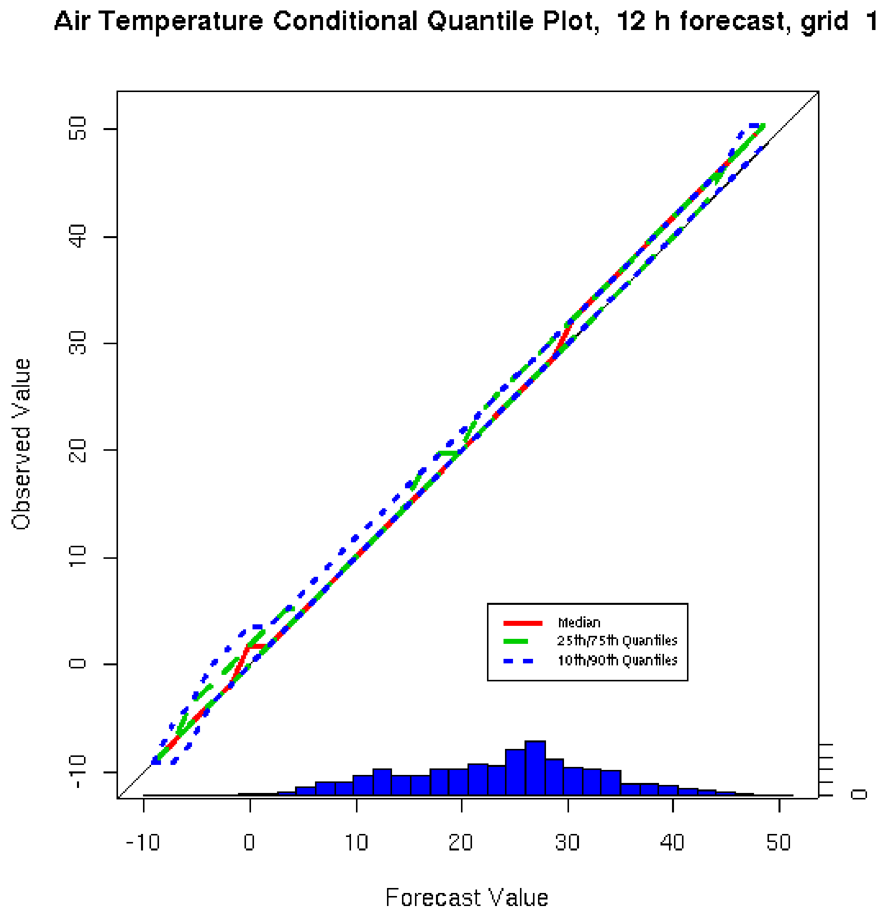

Fig. 3. Conditional quantile plot of the 12 h forecast of the 2 m air temperature data in grid 1.

The histogram of the 12h forecast of air temperature shown in Fig. 3 shows that it is close to the normal distribution. The median, which is the 50% quantile, divides the distribution into two equal parts. Half of the data is located between the 25th and 75th quantiles. In Fig. 3, the median, 25th and 75th quantiles, and 10th and 90th quantiles are located in a very narrow zone. This indicates that the observed and forecast distributions are close each other. The data presented in Fig. 4 shows that the median of the 72 h air temperature forecast has a more complicated structure than the median of 12h forecast. This suggests that the error growth is dependent on the length of the forecast. In Fig. 5, the data for the 120 h forecast is shown. The behavior of median and other quantiles is similar (but slightly larger) than the statistics for the 72 h forecasts. Conditional plots for 72h and 120h show that some un-forecasted bias exists in the results. The general conclusion from these three figures is that the 5 days forecasts produced by the COAMPS model are still reliable and useful, in terms of the 2 m air temperature.

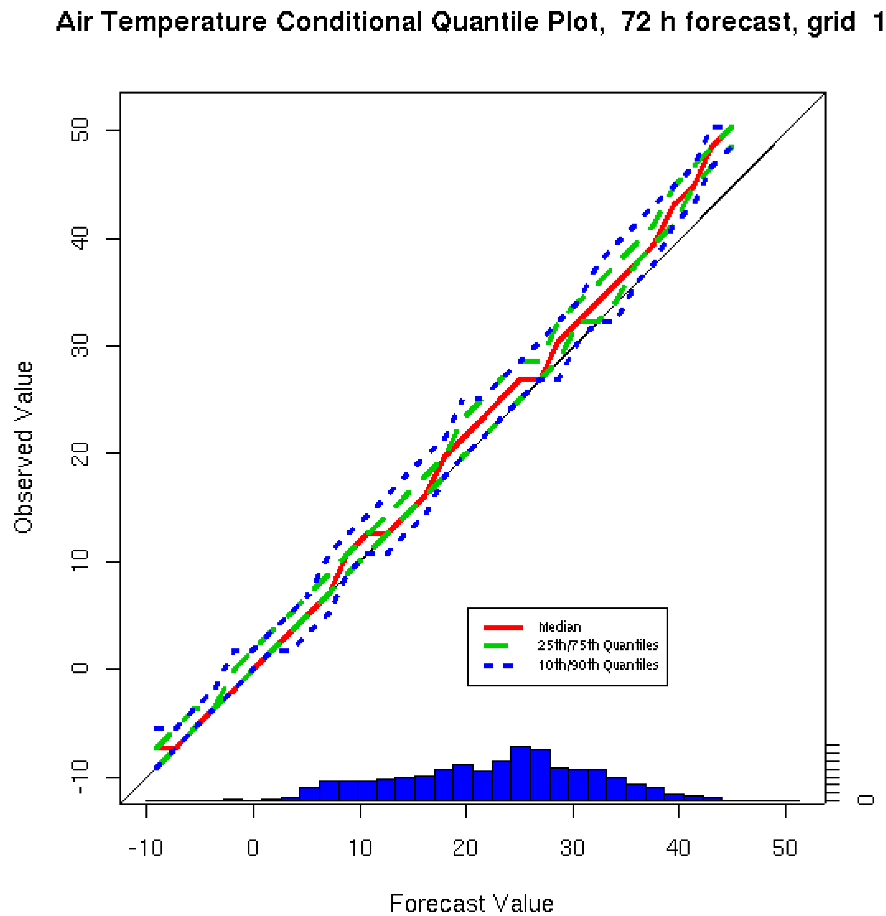

Fig. 4. Conditional quantile plot of the 72 h forecast of the 2 m air temperature in grid 1.

Another field of activity within this project in FY06 was the development of a new solver using a conjugate gradient algorithm with existing block diagonal pre-conditioners. Testing the NRL implementation of the 3D-VAR data assimilation (NAVDAS), Oskar Kapala developed the conditional number estimation in preconditioned conjugate gradient method based on the Lancos algorithm. Using a small grid configuration: kka = 15, m = 30, n = 20, he tested two cases. The first case was used the observational error covariance matrix R, and the condition number was $O(10^4)$. The second case used the whole iteration matrix H^T P H + R, in observation space. Three scenarios were considered: a) matrix without the preconditioner - extremely large condition number, b) matrix with one block diagonal pre-conditioner - condition number $O(10^2)$, and c) a matrix with an average of two block diagonal pre-conditioners - condition number O(10).

In the development of the scheme for the assimilation of the radar reflectivity and radial wind data in the convective scale version of the COAMPS model, Bogumil Jakubiak investigated the features of background errors of basic meteorological elements and the dependence of the background error patterns on horizontal grid length (Jakubiak, 2006). Figure 6 presents examples of highly inhomogeneous structures of the errors at a selected level (left panel) and the vertical distribution of the bias and mean background error (right panel). The main conclusion from such studies is that the SOAR covariance model used in existing Optimal Interpolation (OI) schemes of data analysis is too simple to represent these scales of atmospheric motions. Some ideas of the on-line estimation of error covariance parameters based on the single-sample estimation scheme (Dee, 1995) within the OI framework were formulated and work on the implementation of this method was initiated. In the analysis ensemble approach, the analysis equations are used to transform the background and observation dispersion into the analysis dispersion.

It is extremely difficult to analyze the dynamics of sophisticated and very complex NWP models such as COAMPS. The understanding of the model behavior is crucial for it improvements. Using a simple two-level model of the atmosphere (Brojewski et al., 2006), we tried to learn how the surface temperature and the vertical shear of zonal wind acts on the dynamics of such a model. This is expected to help us better understand the behavior of the COAMPS model.

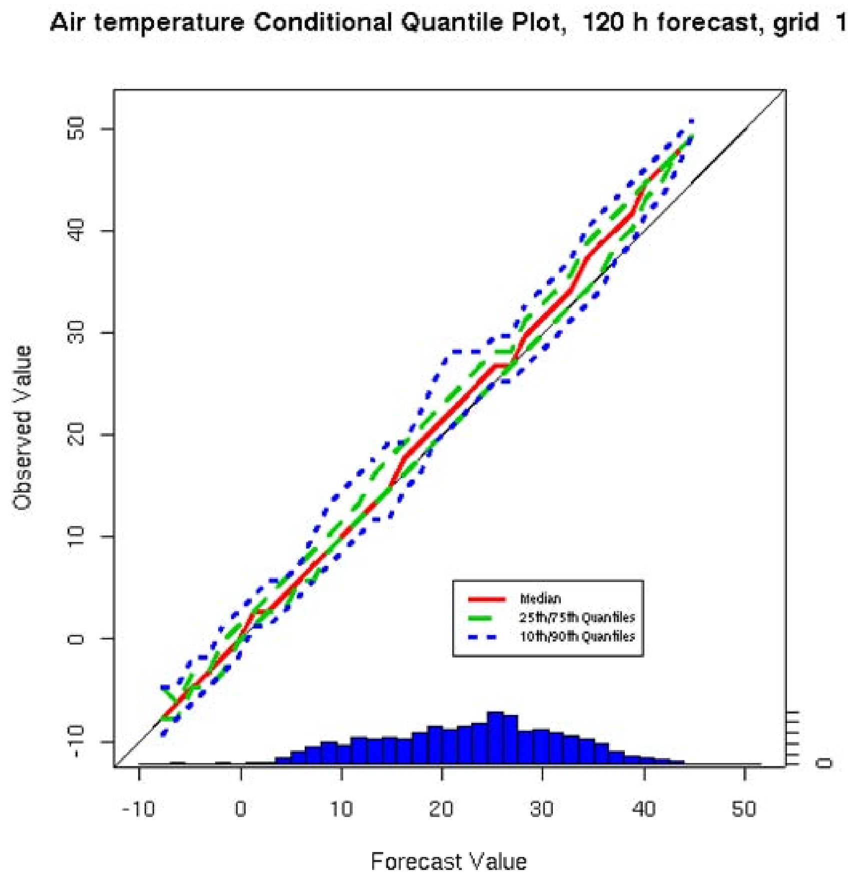

Figure 5. Conditional quantile plot of the 120 h forecast of 2m air temperature data in grid 1.

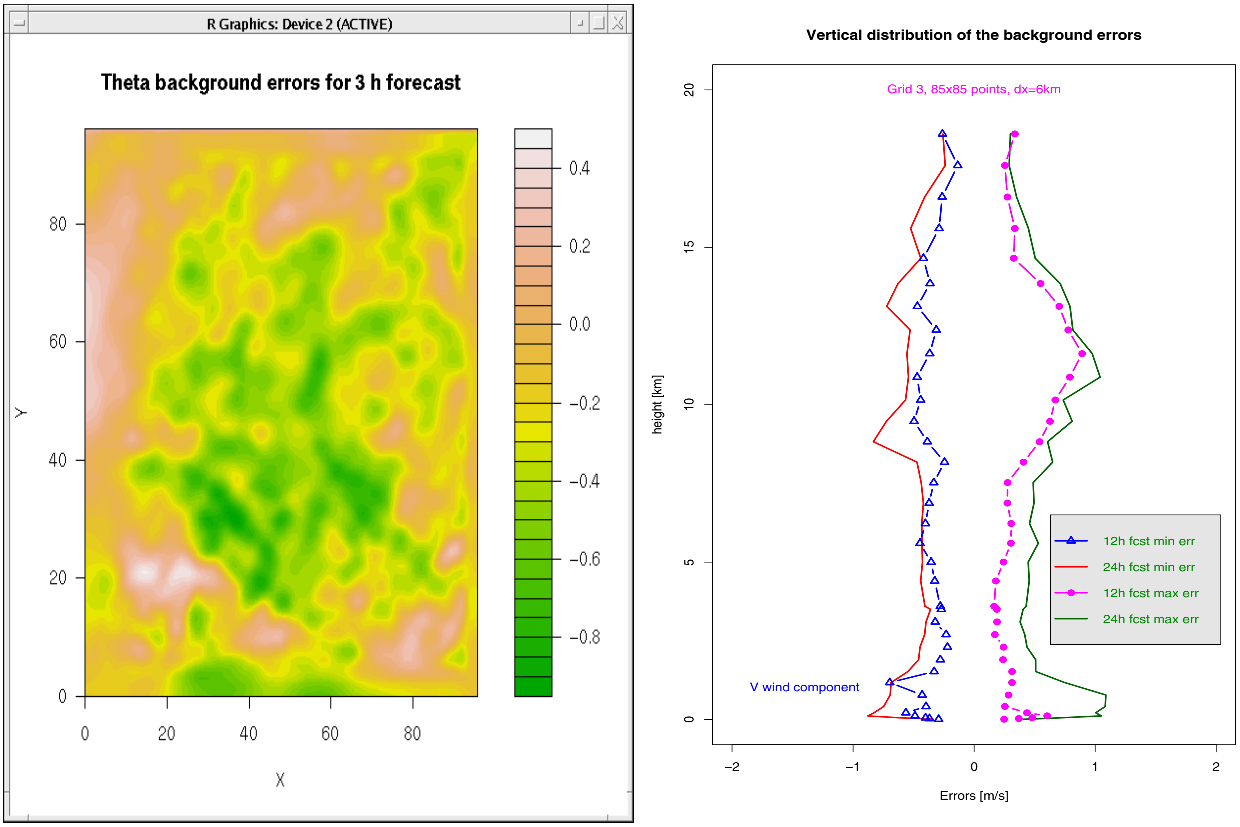

Fig. 6. Background error for convective scale processes. Left panel: background error of V-wind component at level 28 (approximately 1.2 km above of ground level) for the 2 km grid, L35, 97x97 grid points. Right panel: Vertical structure of the bias and mean background error in the 6 km grid for different lead times.

PERSONNEL EXCHANGES AND TRAVEL COMPLEMENTED

Marcin Witek, University of Warsaw – visited NRL, Monterey, CA to work with Piotr Flatau on development of aerosol parameterization in NAAPS and COAMPS models.

Piotr Flatau, NRL – visited University of Warsaw (Poland) to discuss selected aspects of our NICOP project and possibilities to support the pre-olympic regatta in Qingdao. Piotr also visited Qingdao, and took on the role of duty forecaster and prepared regular synoptic forecasts for the Polish sailors using results of the specially-tailored COAMPS system.

Bogumil Jakubiak, University of Warsaw – in Nov-Dec 2005 visited NRL, Monterey, CA, to work with Alan Zhao and Rich Hodur on ensemble Kalman filter data assimilation issues.

Oskar Kapala, University of Warsaw – in Nov 2005 visited NRL, Monterey, CA, to work with Keith Sashegyi on improvement of preconditioning in conjugate gradient algorithm used in NRL 3D-VAR data assimilation system (NAVDAS).

Oskar Kapala, University of Warsaw – participated in High-Resolution Coupled Coastal Prediction Workshop organized by the NATO Undersea Research Centre (NURC, La Spezia, Italy, 29 Nov- 1 Dec 2005) presented "Operational and research applications of the COAMPS system at ICM".

IMPACT/APPLICATIONS

The semi-operational version of the high resolution mesoscale model was implemented. This will improve 5-day forecasting for aviation and for support of Polish troops in Afghanistan and Iraq.

RELATED PROJECTS

2008 Peking Weather Demonstration Project Plans – We collected August 2005 and August 2006 observational data and relevant large scale data analyses and forecasts in anticipation of using COAMPS for the 2008 Olympics WWRP Demonstration Project for China in support of the Polish National Olympic team.

US GODAE project – The Global Ocean Data Assimilation Experiment (GODAE) provides regular, complete descriptions of the state of the ocean and the atmosphere in support of operational oceanography and oceanographic research. We use the GODAE server data for our COAMPS predictions. The GODAE Monterey server is maintained by FNMOC and is sponsored by the Office of Naval Research (ONR).

COST Action 731 project – Propagation of uncertainty in advanced meteo-hydrological forecast systems. Within this action, we started to develop a radar data assimilation scheme using the ensemble Kalman filter approach.

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